Verily, Vortices, Validation, and Vigilance – T&E Lessons for V-22

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Outline

- V-22 T&E Overview
- Verily, OT confirmed DT results
- Our understanding of Vortex Ring State was inadequate
- Validation of emergency procedures was incomplete
- Vigilance – Focus on learning what we need to know

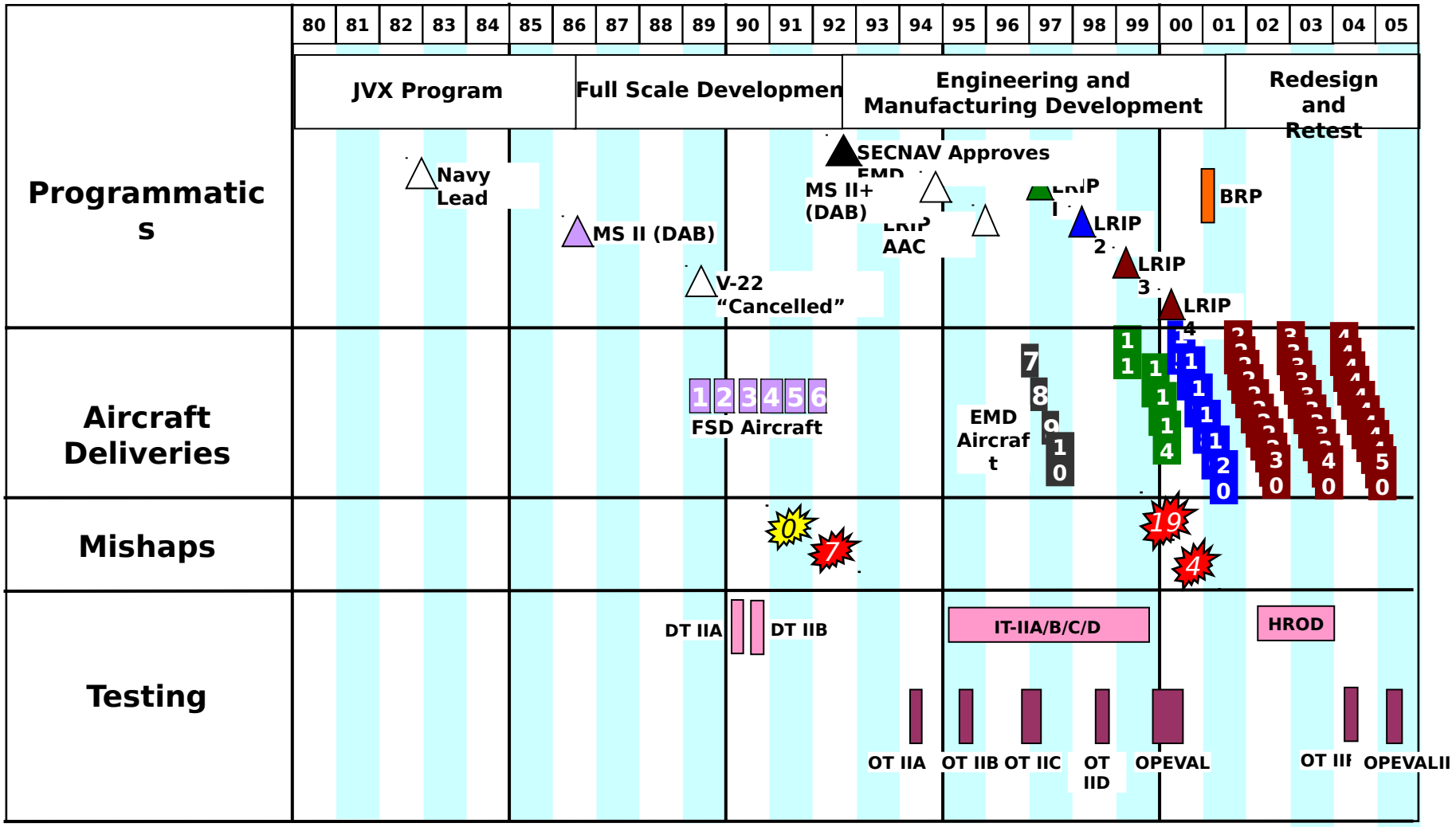
"Men occasionally stumble over the truth, but most of them pick themselves up and hurry off as if nothing had happened."

Winston Churchill

V-22 Overview

- **Takes off and lands like a helicopter**
- **Flies like an airplane**
  - Cruises at 240 knots
  - Max speed 267 knots
- **Will perform USMC medium lift mission**
  - Replaces CH-46E and CH-53D
  - 24 troops or 10,000 pound external lift
- **Will enhance USMC operational flexibility**

V-22 History


80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05
JVX Program
Full Scale Developmen
Engineering and Manufacturing Development
Redesign and Retest
Programmatics
Navy Lead
MS II (DAB)
V-22 "Cancelled"
SECNAV Approves EMD
MS II+ (DAB)
LRIP AAC
LRIP 1
LRIP 2
LRIP 3
LRIP 4
BRP
Aircraft Deliveries
1 2 3 4 5 6
FSD Aircraft
EMD Aircraft
7 8 9 10
11 11 14
11 11 11 11 11 20
23 23 23 23 23 30
33 33 33 33 33 40
44 44 44 44 44 50
Mishaps
0
7
19
4
Testing
DT IIA
DT IIB
IT-IIA/B/C/D
HROD
OT IIA
OT IIB
OT IIC
OT IID
OPEVAL
OT III
OPEVALII

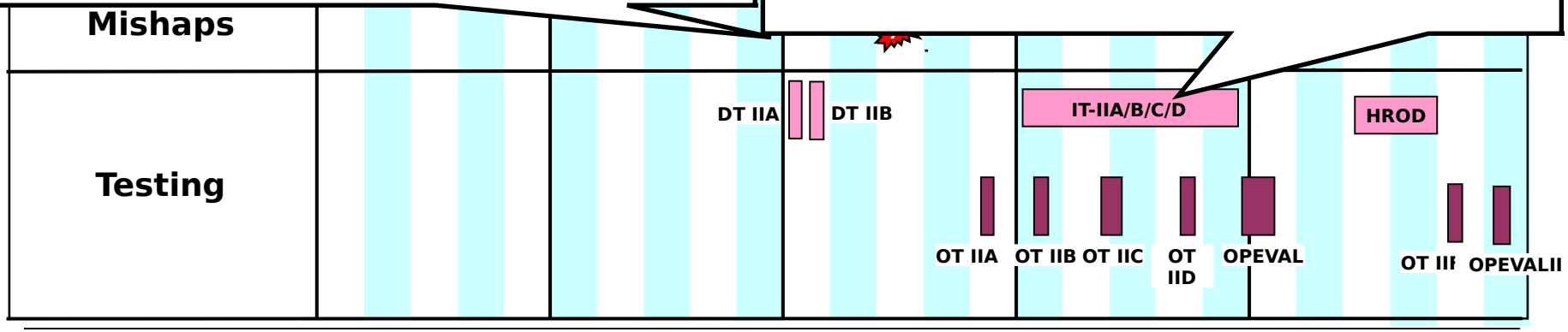
V-22 Developmental Testing

DT-IIA&B

- **Two FSD aircraft, 47 flight hours, 150 hours of ground and engine testing**
- **Demonstrated potential for intended missions**
- **5 Enhancing Characteristics**
- **57 Part I Deficiencies**
  - Excessive pilot workload in hover
  - Inaccurate vertical velocity indicator
  - Excessive rotor downwash
  - Unreliable Hydraulic System
- **Failed DT Reliability and Maintainability thresholds**

IT-IIA/B/C/D

- **5 years and 1,374 flight hours of integrated developmental testing**
- **Started with FSD aircraft and concluded with EMD aircraft**
- **Final report - 30 Part I Deficiencies**
  - Low reliability
  - Excessive lateral control inputs required
  - Navy uses Waiver process to acknowledge failures and **proceed to OPEVAL!**



V-22
OPEVAL

- **Adequate Test Scope**
  - 804 flight hours on 4 aircraft from first low-rate initial production lot
  - Multiple test locations on East/West coast and Yuma Desert
  - Included three periods of shipboard testing
  - Numerous representative mission segments or tasks
  - Demonstrated mission profiles associated with Key Performance Parameters (KPPs)
- **DOT&E: Effective, but with concerns**
  - Vortex Ring State
  - Operational limitations
- **DOT&E: Not Suitable**
  - Marginal mission reliability
  - Excessive maintenance manpower requi
  - Inadequate availability
  - Inaccurate and incomplete documentatic
  - Non-useful diagnostics
  - Poor interoperability, notably communications
  - Shipboard capability to handle multiple MV-22s untested

Funding priority had been placed on meeting KPPs

Verily, DT was correct!

Failures that had been found had not been fixed

Vortex Ring State during OPEVAL

April 8, 2000 – Marana, Arizona

High Gross Weight

Night Landing

Under Goggles

Airspeed: 180 Kts

ROD: >2500 fpm

Airspeed: 100 Kts

AGL: 1000 ft

High Rate of Descent with low airspeed resulted in Vortex Ring State Condition

HROD DT had been curtailed. OT pilots were not sensitive to VR

ROD: >2000 fpm

Airspeed: 40 Kts

AGL: 300 ft

10-15 Kt Tail Wind

Program Interrupted

- **5 Dec 2000, Milestone III Briefing**
- **ASN (R,D&A) placed FRP decision on hold to get answers on 6 issues**
- **Among his concerns were the issues raised by DOT&E**

11 Dec 2000

New River, NC

Routine Training

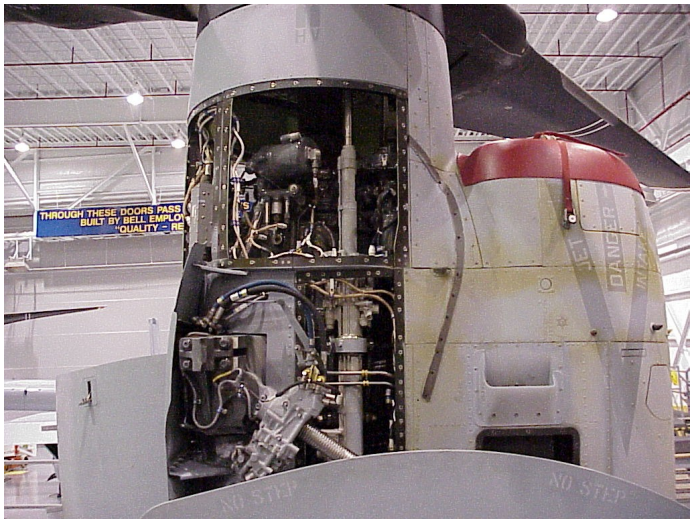
Airspeed: 178 Kts

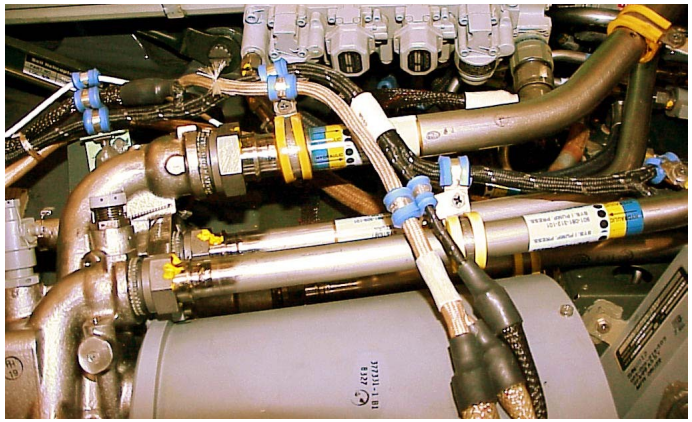
AGL: 1600 ft

1923 hours

Hydraulic Line Failure

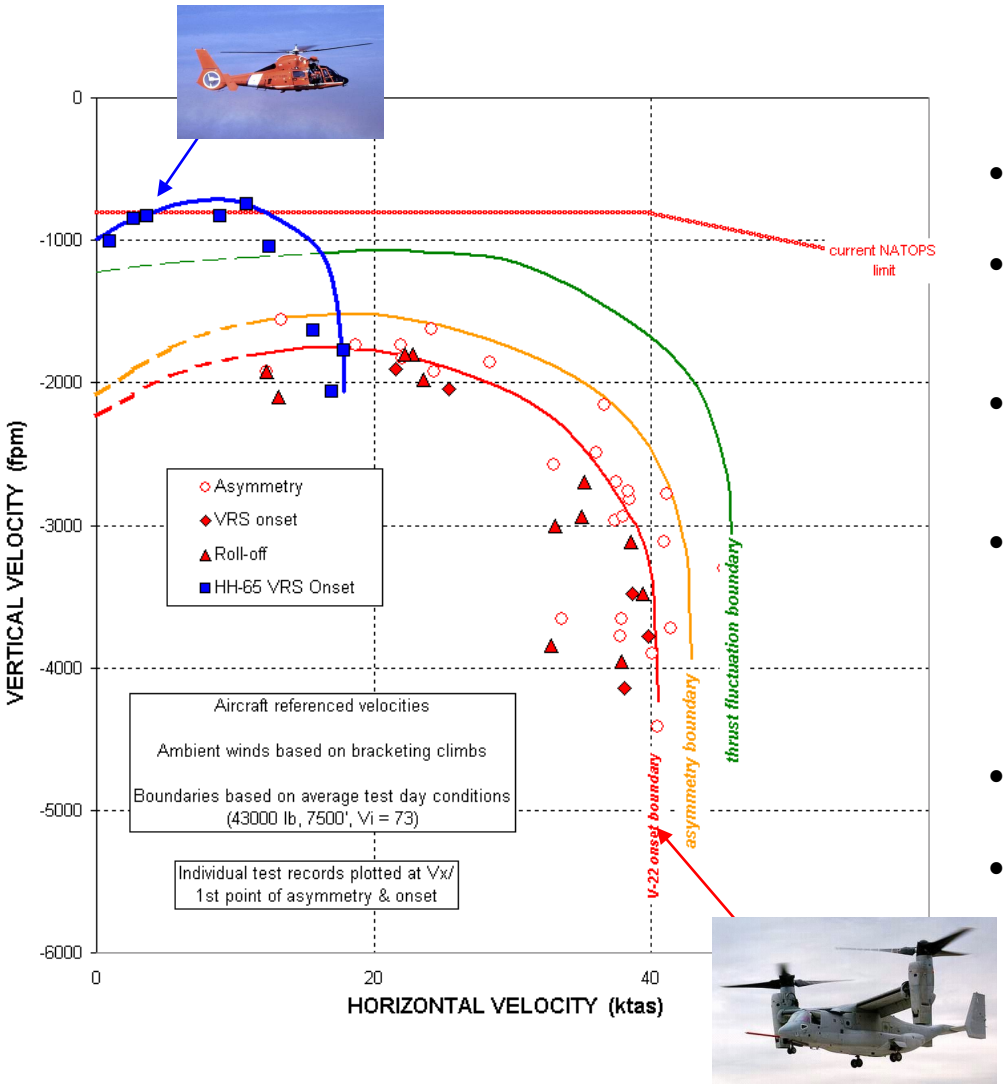
Incomplete Validation





- **Dual hydraulic failures tested in the laboratory**
  - Software gave correct warning
- **Emergency procedures tested in simulators**
  - Pilots knew how to respond to warnings
- **End-to-end simulation of hydraulic failures coupled with pilot reaction never tested**
- **Pilot-in-the-loop testing might have discovered the software anomaly**

Vortex Ring State since OPEVAL



- V-22 returned to flight May 2002
- Over 1150 hours DT, much in HROD
- Testing confirmed VRS model predictions
- Onset of VRS occurs at higher rates of descent, but higher airspeeds than conventional helicopters
- 12 Rolloffs to date
- Forward tilt of nacelle provides robust recovery in most situations

Vigilance –
Refocus the program

- **What do we need to learn?**
  - Address issues from the Blue Ribbon Panel, NASA Ames Study, DOT&E, and Congress.
- **Fix what we can.**
  - Redesigned flight control software.
  - Re-rout hydraulic lines and electrical wiring in the nacelles
  - More secure fasteners and better access in the nacelles.
- **Proceed with caution**
  - Prior to return to flight, conduct extensive hardware-in-the-loop, pilot-in-the-loop testing
  - A detailed, event-based flight test program began in May 2002.
  - Progressive lengthening of inspections from 2 to 35 hours.

Vigilance – Understand VRS

- **If Marana conditions were flown today, the V-22 would respond in the same way.**

- **What has changed:**
  - Knowledge about VRS consequences is widespread in the V-22 community.
  - Extensive HROD testing confirmed VRS envelope; operating limitations appear adequate for normal conditions; more investigation underway
  - Simulators, flight syllabus, and NATOPs emphasize avoiding the phenomenon.
  - HROD warning system is present for both pilots and appears functional.
  - Vertical speed indicator has been improved.
  - VRS recovery techniques at altitude have been demonstrated and are understood.

Vigilance – Return to Operational Testing

- **OPEVAL I demonstrated KPPs in limited operational environments.**
  - V-22 demonstrated significant improvements in speed, range, and maneuverability.
- **Some pure-helicopter mission tasks are better performed by CH-53E & UH-1Y.**
  - Inherent tiltrotor design raises some operational limitations.
  - OPEVAL II will evaluate the operational impact of these limitations.
- **OPEVAL II will focus more on mission performance with multiple aircraft in ship-to-shore operations.**

Conclusion

The V-22 program illustrates two approaches:

Focus on cost and schedule

- ✗ Curtailed developmental testing
- ✗ Deferred correction of reliability failures
- ✗ Meet KPPs, but only in limited operational environments

Be vigilant and proceed with caution

- ✓ Identify and address all the issues
- ✓ Eliminate known reliability failures
- ✓ Revise operational concepts as needed
- ✓ Begin OT only after planned testing is finished
- ✓ Progress to realistic combat operations in OT

The second approach is more appropriate for T&E of new rotorcraft designs